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The Effect of Shape and Weight Towards the Performance of Simple Adaptive Median Filter in Reducing Impulse Noise Level from Digital Images

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Abstract— **Recently, Simple Adaptive Median (SAM) filter has been introduced for the purpose of reducing the impulse noise level in digital images. SAM filter, which uses square filter as its basis, has an ability to change the size of the filter, spatially, based on the approximated local noise level. This paper investigates the effect of shape and weight into the performance of SAM filter in terms of quality improvement, and also execution time. In this work, SAM filter has been compared with its three new derivatives. These three new methods are Circular SAM (CSAM), Weighted SAM (WSAM), and Weighted CSAM (WCSAM). For the purpose of evaluation, fifty test images of size 1600×1200 pixels have been used as the test images. The results show that the performance of these methods is almost identical. All methods successfully restore the images corrupted up to 95% of impulse noise. Circular filter and weighting process slightly improve the performance of SAM. However, circular filter dramatically increases the processing time due to its complicated implementation.**

Keywords- noise reduction; salt-and-pepper noise; impulse noise; adaptive filter

I. INTRODUCTION

Median filter is one of the popular methods to be employed to reduce impulse noise level from corrupted images. However, the conventional median filter does not have the ability to differentiate between noise free and noisy pixels. Therefore, all pixels in the image are treated equally. As a consequence, the conventional median filter eliminates fine details, such as thin lines and corners, and results the blurring or distortion in the image [1].

Many variations and improvements of median filter have been introduced in literature. One of the branches of median based filter is the adaptive median filter, where the size of the filter applied to an individual pixel is determined based on the approximation of the local noise level. Work by Hwang and Haddad [2], for example, approximate the noisy pixels based on the minimum, maximum and median intensity values contained inside a local window. At each pixel location, they initialize the filter with a smaller window size first. Then, the size of the filter will be expanded, until certain conditions are met.

Switching median method is one type of the median based methods. This method consists of two stages; noise detection, and noise removal. Switching median filter only filters the pixels that are assumed to be noisy pixels, while keep the "noise free" pixels unaltered. An example of switching median filter is presented in [3].

Recently, a new method known as Simple Adaptive Median (SAM) filter has been proposed in [1]. This method is a hybrid between the adaptive median filter, with the switching median filter. In terms of root mean square error (RMSE) value, and processing time, SAM successfully removes the impulse noise up to noise percentage of 95%.

This paper fused other median filter variations into SAM, namely circular median filter (e.g. [4]) and weighted median filter (e.g. [5]). As a consequence, three new methods based on SAM have been proposed. They are Circular SAM (CSAM), Weighted SAM (WSAM), and Weighted CSAM (WCSAM). The objective of this work is to investigate the advantage of embedding circular filter or weighting into SAM.

II. SIMPLE ADAPTIVE MEDIAN FILTER (SAM)

Following the framework of switching median filter, SAM filter is constructed from two stages, which are noise detection, and noise cancellation. The adaptive median filter concept is employed in noise cancellation. Although SAM has been described in [1], in order to make this article to be self-contained, brief descriptions on two stages of SAM are briefly given by the following two subsections.

A. Stage 1: Noise Detection

This stage is needed to identify the "noisy pixel" candidates from an image of size $M \times N$ pixels. It is known that for an image with L intensity levels, the pixels corrupted by the impulse noise are usually digitized into either the minimum or the maximum values of the dynamic range (i.e. 0 or L-1). Therefore, at each pixel location (x, y), we mark binary mask α by using the following equation:

$$\alpha(x,y) = \begin{cases} 1 & : \quad f(x,y) = 0 \text{ or } L-1 \\ 0 & : \quad \text{otherwise} \end{cases} \tag{1}$$

where f is the input image, and the value 1 and 0 represent the "noisy pixel" and "noise free pixel", respectively.

Next, the rough approximation of the noise level η in the image is calculated based on (2).

$$\eta = K/(MN) \tag{2}$$

where

$$K = \sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\alpha(x,y) \tag{3}$$

The binary mask α, and η will be used in the second stage.

B. Stage 2: Noise Cancellation

In this stage, the output image g is obtained by using the switching median filter framework as defined by (4).

$$g(x,y) = \begin{cases} f(x,y) & : \quad \alpha(x,y) = 0 \\ m(x,y) & : \quad \text{otherwise} \end{cases} \tag{4}$$

where m is the median value obtained from our adaptive method. In SAM, the value of m is found by using the following algorithm:

1. Initialize the size of the square filter $W = 2R_{\min}+1$, where $R_{\min}$ is an integer value calculated using (5).

   $$R_{\min} = \left\lfloor 0.5\sqrt{7/(1-\eta)} \right\rfloor \tag{5}$$

   where $\lfloor Z \rfloor$ presents the floor value of Z.
2. Based on the binary mask α, compute the number of "noise free pixels" contained in the contextual region of size $W\times W$, as defined by the filter.
3. If the number of "noise free pixels" is less than eight pixels, increase the size of the square filter by two (i.e. $W = W+2$) and return to step 2.
4. Calculate the value of $m(x,y)$ based on the "noise free pixels" contained in window of size $W\times W$.
5. Update the value of $g(x,y)$ by using (4).

Results in [1] show that the performance of SAM surpasses some of the state-of-art methods, which are the adaptive based method by Hwang and Haddad [2], the switching based method by Zhang and Karim [6] and the fuzzy based method by Luo [7]. SAM is superior in terms of root mean square error (RMSE) value and processing time.

III. MODIFICATIONS TO SAM FILTER

In this paper, three modified versions of SAM have been investigated, which are Circular SAM (CSAM), Weighted SAM (WSAM), and Weighted CSAM (WCSAM). These modifications are based on the shape of the filter, and the weighting process. Examples of these filters are shown in Fig. 1.

CSAM shares the same framework with SAM, except that CSAM uses circular filter instead of the square filter. Circular filter can minimize the artifacts associated with square kernel [8]. Furthermore, the pixels at the corner of the square filter are not significantly contributing to the finding of an accurate median value [4]. The implementation of CSAM is following the algorithm presented in Section II.*B*, where W presents the diameter of the filter.

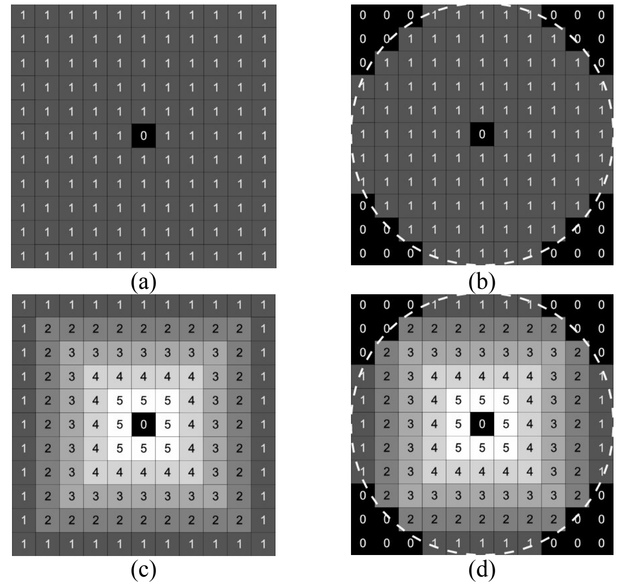

Figure 1. Filters with dimensions of 11×11 pixels. The numbers inside the filter present the weights. (a) SAM filter. (b) CSAM filter. (c) WSAM filter. (d) WCSAM filter.

Weighting process also has been introduced into both SAM and CSAM, producing WSAM and WCSAM, respectively. The weighting process gives more weight to the center pixels of the filter. By doing this, the filter will has better local image preservation ability [5].

The implementation of both WSAM and WCSAM still follow the algorithm given in Section II.*B*, except that the weighting process is added into step 3 and step 4. These weights correspond to the number of occurrences of pixel underneath the mask, for the determination of $m(x, y)$. The outermost pixels of the filter will be given weight of one. The weight function is a linear function, monotonically increasing towards the center of the kernel, based on Chebyshev distance. The weight of the pixel at the middle of the kernel (i.e. the innermost pixel) is given the integer value of the radius of the equivalent circular kernel.

IV. EXPERIMENTAL RESULTS

In this work, 50 grayscale images with eight bit depth per pixel (i.e. L=8), have been used as the test images. All of these images are with dimensions of 1600×1200 pixels. These "impulse noise free images" are denoted as e. Then, we contaminate these images with Q% of impulse noise, where $0.5Q$% are the positive impulses, and $0.5Q$% are the negative impulses. These corrupted images are denoted as f. Next, image f is processed by using SAM, CSAM, WSAM, and WCSAM, independently. The restored image is then denoted as g. The results are then evaluated based on mean square error (MSE), processing time t, and by visual inspection.

MSE value is used to evaluate the correction error of the method. This measure is defined by the following equation:

$$\mathrm{MSE} = \frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}\left[g(x,y) - e(x,y)\right]^2 \quad (6)$$

Based on (6), it is shown that a good noise filtering method should produce a small MSE value, where the output image g is mostly resembles the original uncorrupted image e.

Table 1 shows the average MSE value obtained from 50 test images. This table clearly shows that the weighted methods (i.e. WSAM and WCSAM) are able to produce smaller MSE values as compared with SAM and CSAM. This is because both WSAM and WCSAM have better local image preservation ability. WCSAM produces the smallest MSE value for images corrupted by 0% to 75% of impulse noise. For the noise level greater than 75%, WSAM is the one with the smallest MSE.

TABLE I. AVERAGE MSE VALUE TAKEN FROM 50 TEST IMAGES

Noise Level (%)	SAM	CSAM	WSAM	WCSAM
0	0.059	0.054	0.053	**0.050**
5	3.446	3.173	3.058	**2.825**
15	14.693	12.900	12.193	**10.776**
25	28.378	24.654	23.202	**20.451**
35	43.025	37.532	35.224	**31.451**
45	58.724	52.302	48.516	**44.484**
55	77.851	71.960	65.004	**62.026**
65	105.593	99.480	88.473	**86.599**
75	143.471	137.158	120.526	**120.236**
85	196.217	190.564	**168.511**	169.734
95	298.084	290.186	**270.592**	271.766

Table 2 shows the average processing time t, measured from 50 test images. It is worth noting that circular based methods (i.e. CSAM and WCSAM) have longer processing time. This is because the implementation of circular filter is more complicated compared with the square filter. WCSAM has the longest processing time as this method not only involved with circular filter, but also the weighting process.

TABLE II. AVERAGE PROCESSING TIME TAKEN FROM 50 TEST IMAGES

Noise Level (%)	SAM	CSAM	WSAM	WCSAM
0	0.014s	0.017s	0.015s	0.019s
5	0.054s	0.101s	0.060s	0.108s
15	0.176s	0.377s	0.201s	0.425s
25	0.325s	0.715s	0.381s	0.782s
35	0.495s	1.056s	0.568s	1.169s
45	0.643s	1.454s	0.728s	1.649s
55	0.827s	2.198s	0.940s	2.501s
65	0.922s	3.138s	1.186s	3.929s
75	1.354s	5.120s	1.642s	6.637s
85	1.757s	8.143s	2.333s	12.442s
95	3.989s	29.785s	6.289s	48.055s

Fig. 2 shows the results obtained from one of the test images. This figure shows that all of these four methods are able to produce almost identical results, and perform well for highly corrupted images. From the visual inspection on the zoomed version of the square region presented in the figure, the results show that the performance of WSAM and WCSAM is slightly better than SAM and CSAM. WSAM and WCSAM have better local detail preservation ability.

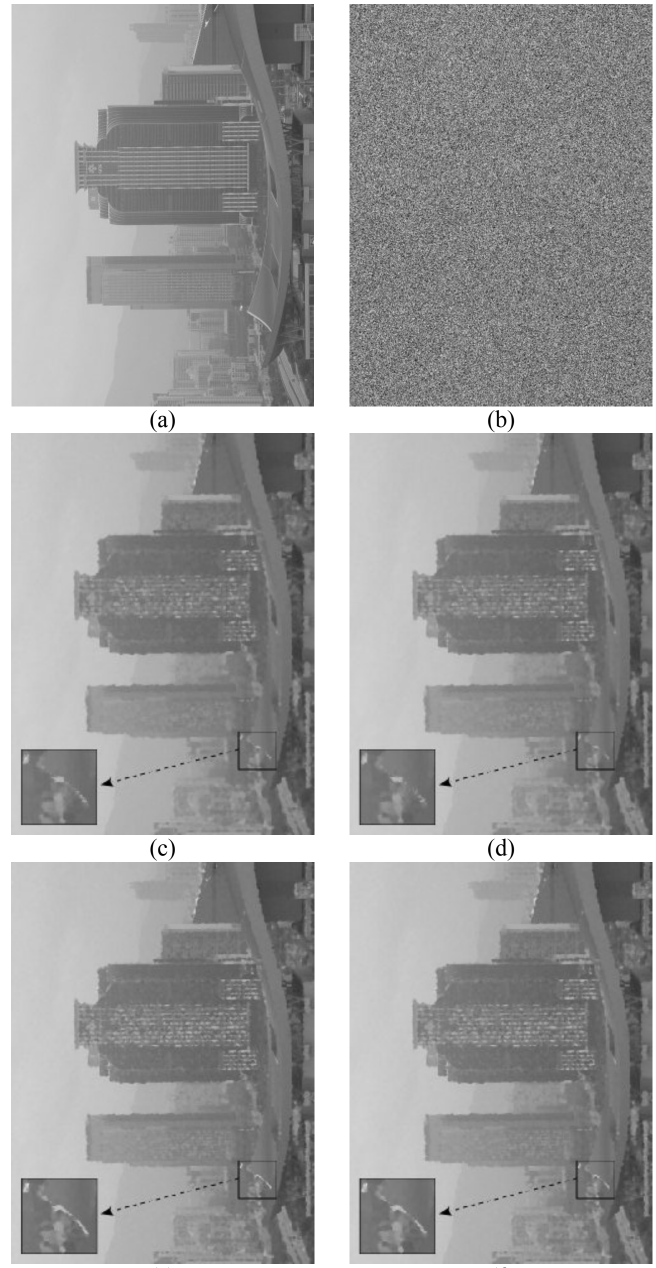

Figure 2. One of the test images. (a) Input image. (b) Image (a) after corrupted by 95% of impulse noise. (c) SAM-ed of image (b). (d) CSAM-ed of image (b). (e) WSAM-ed of image (b). (f) WCSAM-ed of image (b).

V. CONCLUSION

In this paper, the contributions of circular filter and weighting process towards the performance of SAM have been investigated, in terms of MSE value, processing time, and by visual inspection. Visually, all methods produce almost equivalent results. Circular filter and weighting process slightly reduce the MSE value. However, circular filter requires a longer processing time, and thus should be avoided in the design for real-time processing system.

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